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(45) **Date of Patent:** **May 17, 2016**

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(21) Appl. No.: 14/634,890

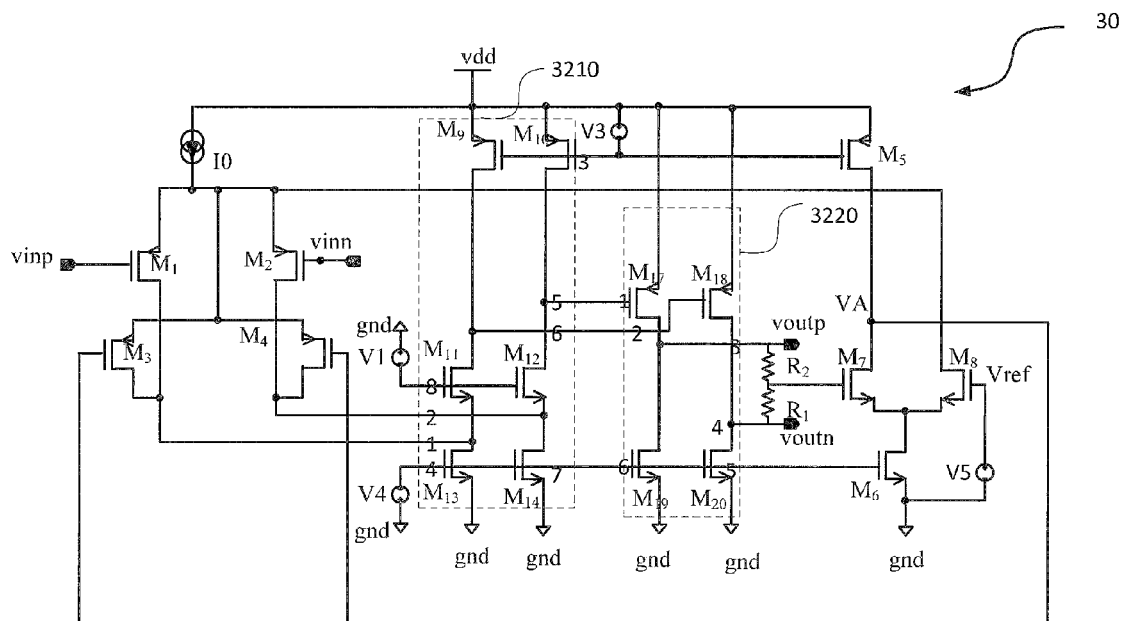
(57) **ABSTRACT**

An operational amplifier comprises an input pair, an aiding unit, an even number of amplification stages, a feeding unit, a first current source, a second current source. Both the input pair and the aiding unit are connected to the first current source. The input pair receives differential input voltage. Both the input pair and the aiding unit are further connected to a first stage of the even number of amplification stages. The even number of amplification stages are connected in series, and the last stage of the amplification stages outputs differential output voltages. The feeding unit is configured to receive a common mode voltage of the differential output voltages, and feeds a voltage on a first node of the feeding unit back to the aiding unit so as to provide bias voltage to the aiding unit. The aiding unit avoids dead lock of the input pair.

22 Claims, 8 Drawing Sheets

(52) **U.S. Cl.**
CPC *H03F 3/45645* (2013.01); *H03F 2200/153*
(2013.01)

(58) **Field of Classification Search**
CPC H03F 3/45
USPC 330/258, 260, 253
See application file for complete search history.



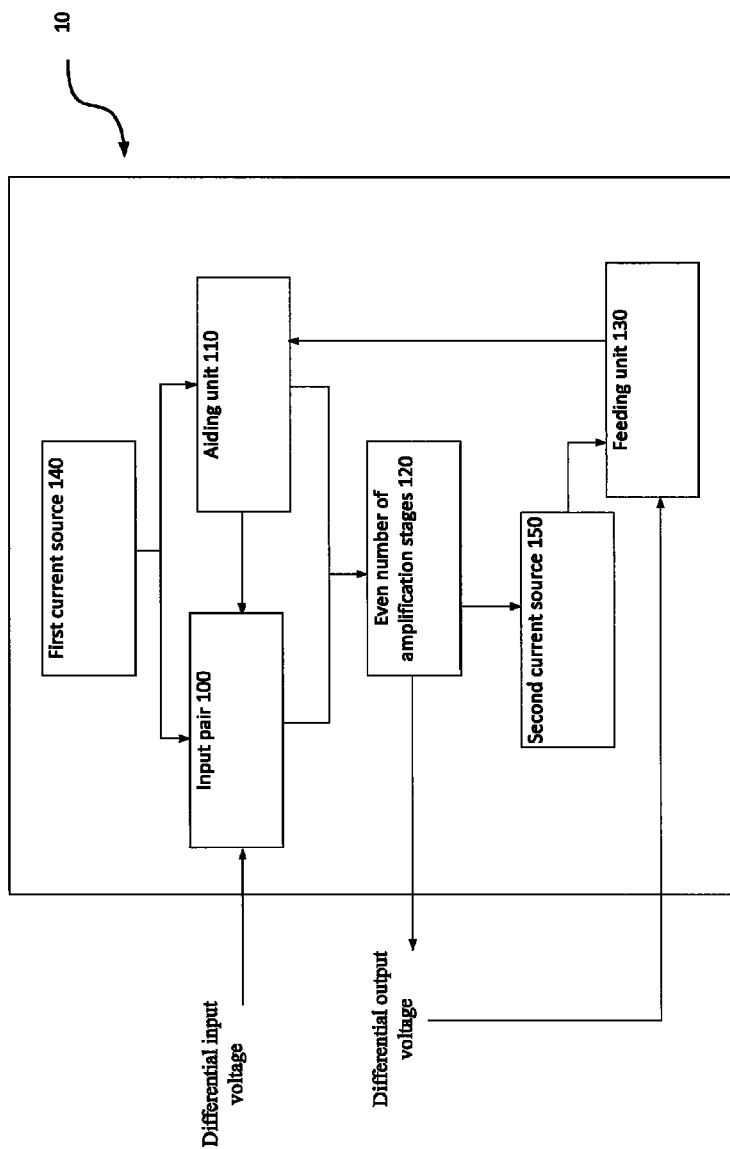


FIG. 1

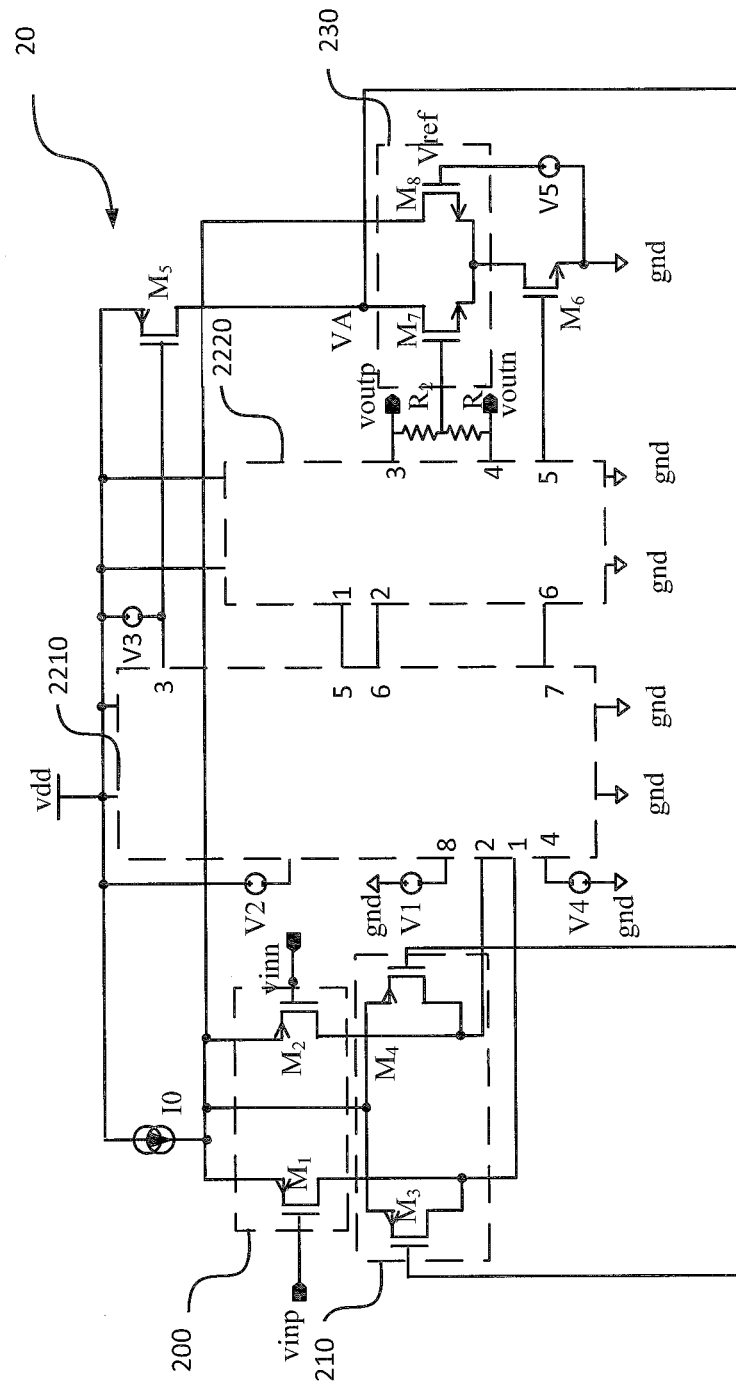


FIG. 2

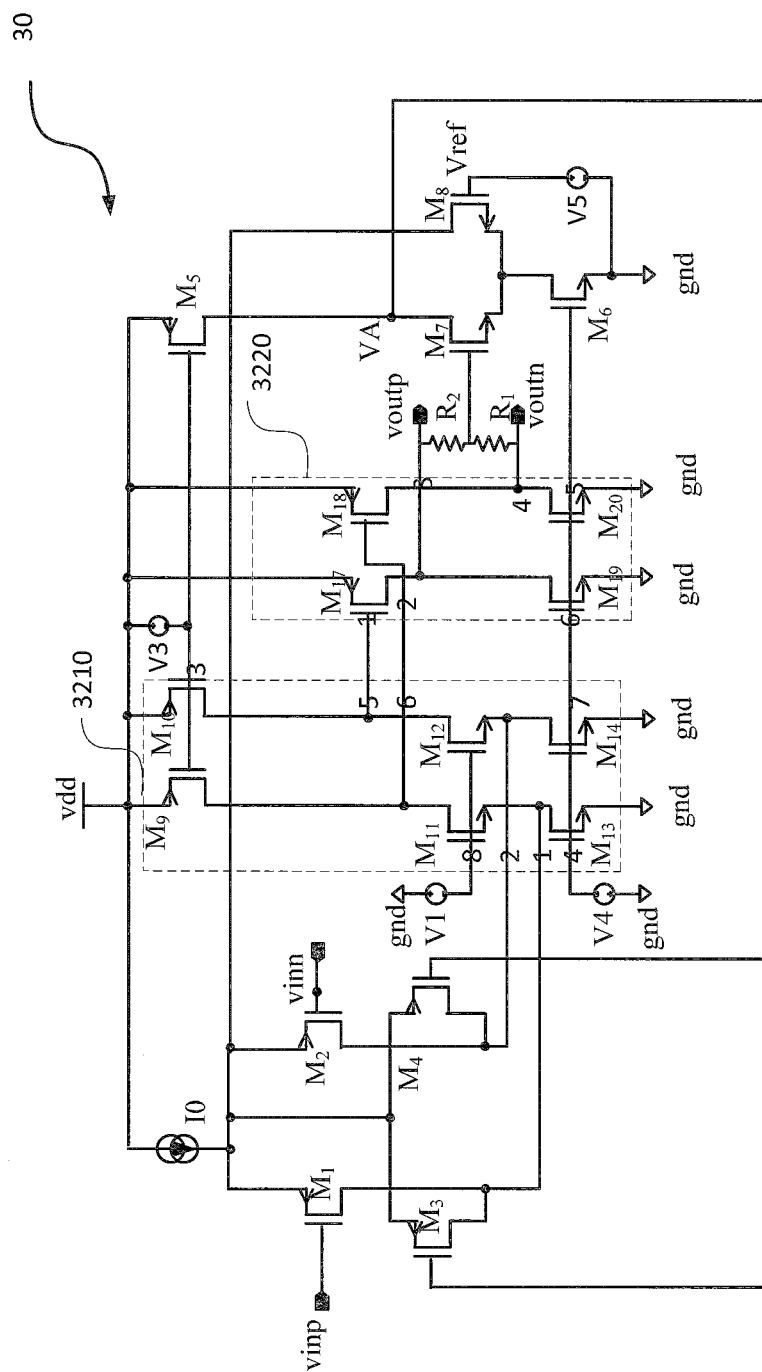


FIG. 3.

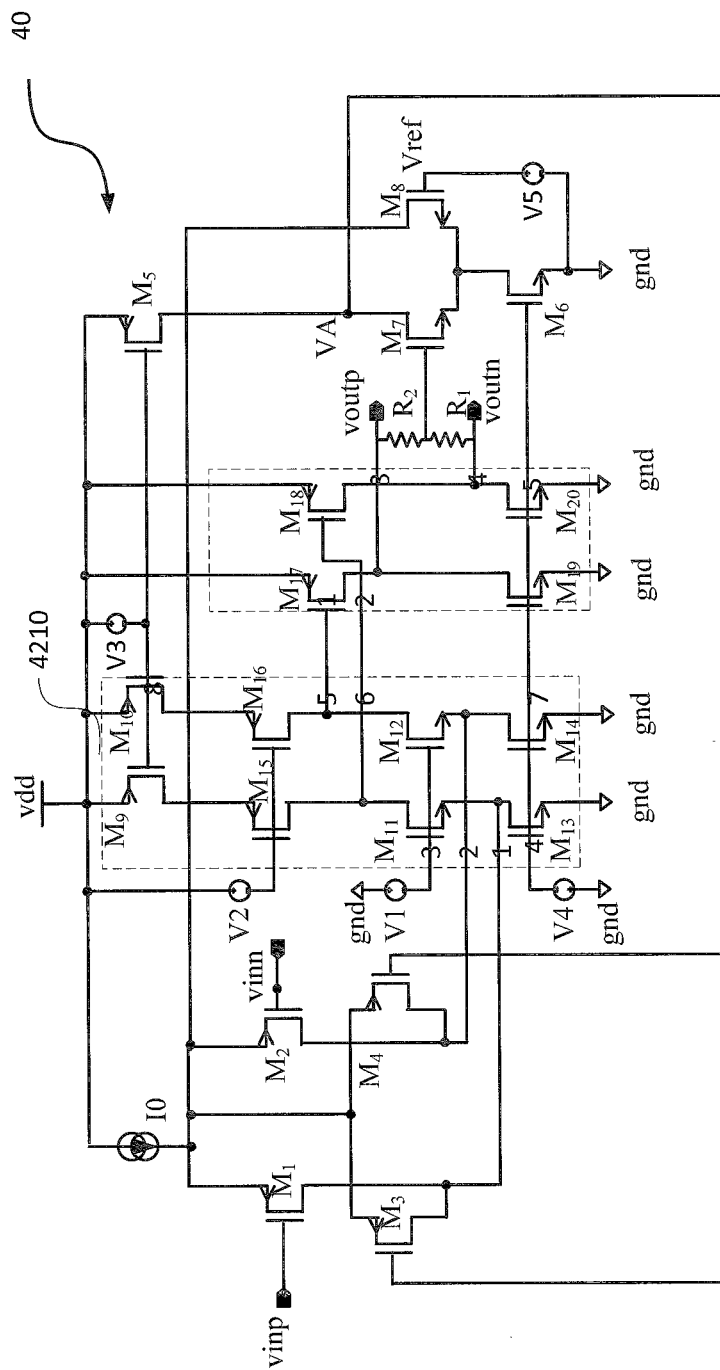


FIG. 4

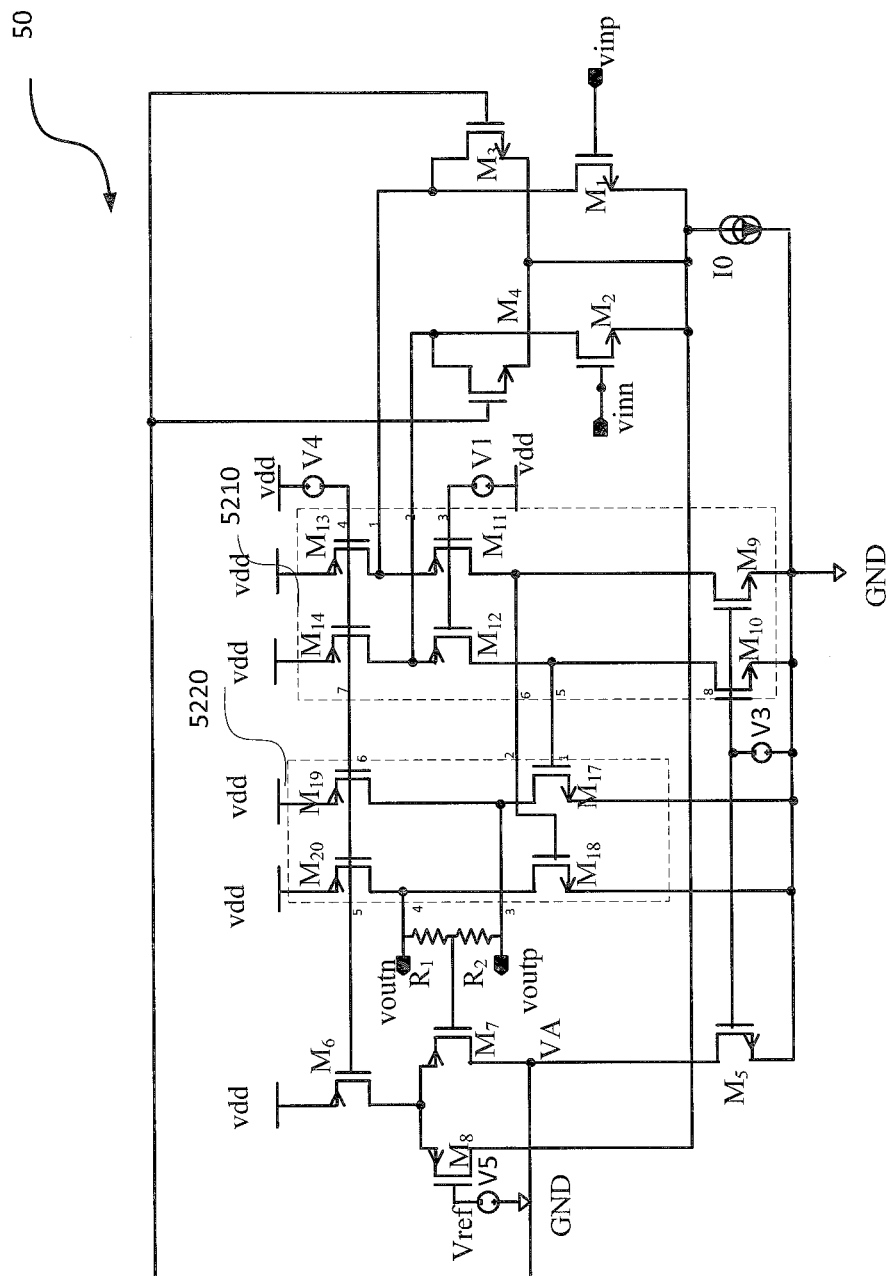


FIG. 5

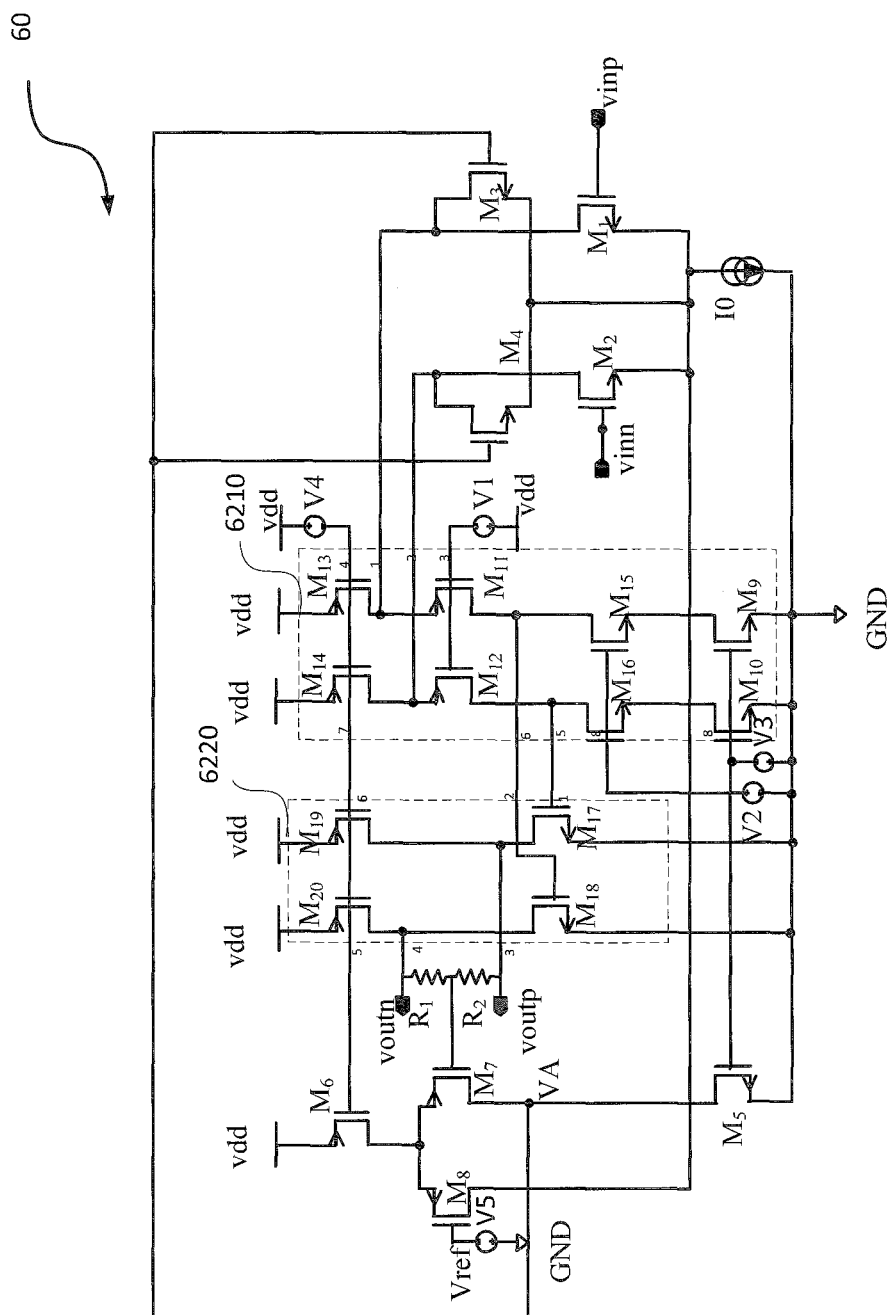


FIG. 6

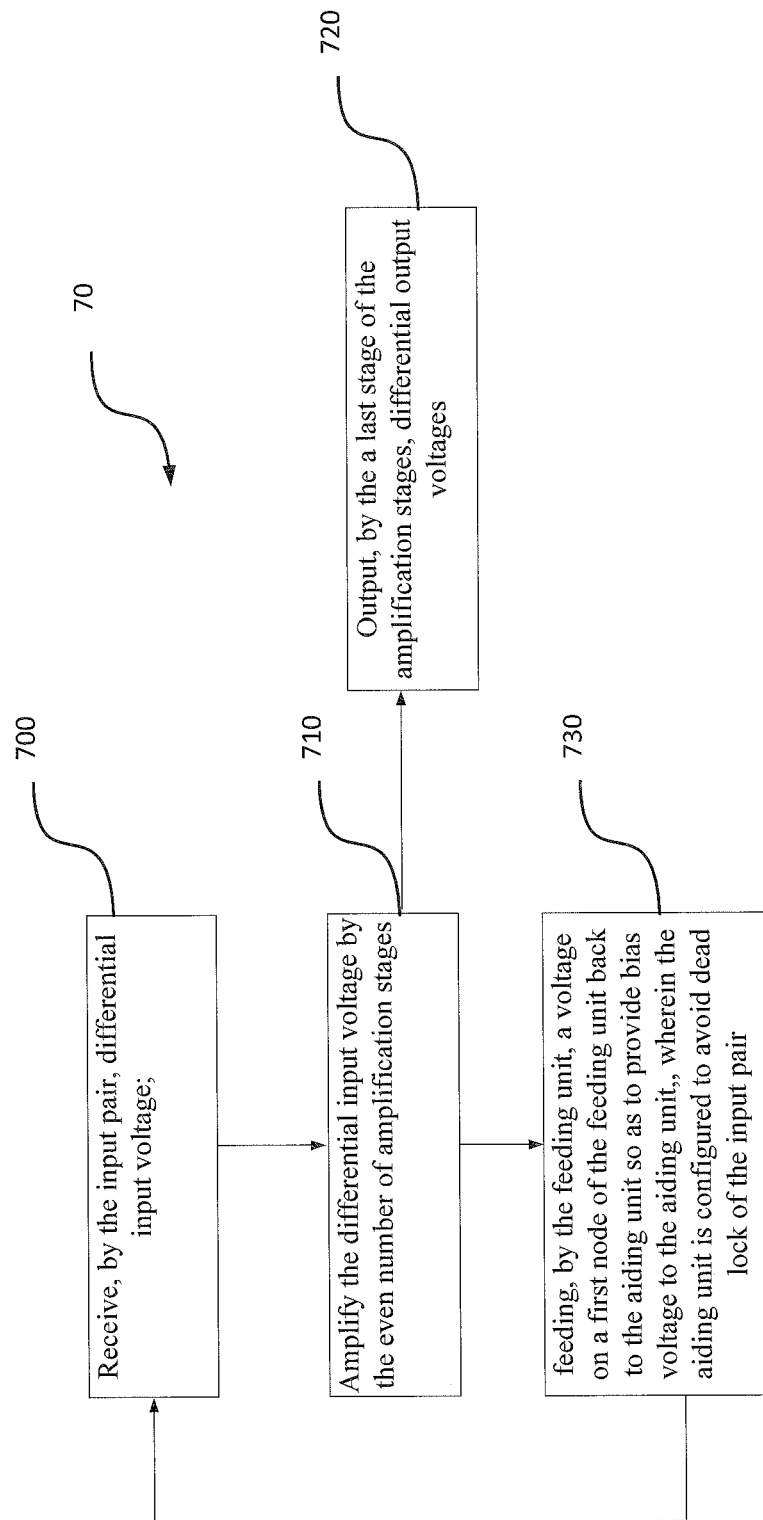


FIG. 7

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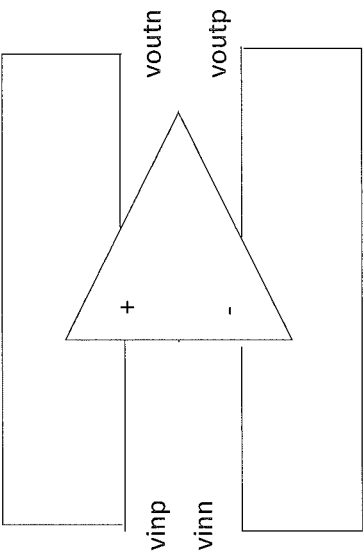


FIG. 8

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OPERATIONAL AMPLIFIER AND METHOD OF AMPLIFYING WITH THE OPERATIONAL AMPLIFIER

CROSS REFERENCE TO RELATED APPLICATION

This application claims priority to Chinese Application No. 201510051993. X entitled "Operational amplifier and method in the operational amplifier," filed on Jan. 30, 2015 by Beken Corporation, which is incorporated herein by reference.

TECHNICAL FIELD

The present application relates to circuits, and more particularly but not exclusively to an operational amplifier and a method of amplifying with the operational amplifier.

BACKGROUND

Conventional operational amplifiers use an assistant voltage to feed to differential voltage input pair. However, such assisting voltage is hard to obtain in real application. Therefore, it is desirable to have an operational amplifier with appropriate assisting voltage.

SUMMARY OF THE INVENTION

In an embodiment, an operational amplifier comprises an input pair, an aiding unit, an even number of amplification stages, a feeding unit, a first current source, a second current source; wherein both the input pair and the aiding unit are connected to the first current source, the input pair is also configured to receive differential input voltage, and both the input pair and the aiding unit are further connected to a first stage of the even number of amplification stages; the even number of amplification stages are connected in series, and a last stage of the amplification stages is configured to output differential output voltages; the feeding unit is configured to receive a common mode voltage of the differential output voltages from the last stage, and is configured to feed a voltage on a first node of the feeding unit back to the aiding unit so as to provide bias voltage to the aiding unit, wherein the aiding unit is configured to avoid dead lock of the input pair.

Another embodiment discloses a method in an operational amplifier, wherein the operational amplifier comprises an input pair, an aiding unit, an even number of amplification stages, a feeding unit, a first current source, a second current source; wherein first nodes of both the input pair and the aiding unit are connected to the first current source, and third nodes of both the input pair and the aiding unit are connected to a first stage of the even number of amplification stages; the even number of amplification stages are connected in series; the feeding unit is configured to receive a common mode voltage of the differential output voltages from the last stage; where the method comprises receiving, by the input pair, differential input voltage; amplifying the differential input voltage by the even number of amplification stages; outputting, by a last stage of the amplification stages, differential output voltages; feeding, by the feeding unit, a voltage on a first node of the feeding unit back to the aiding unit so as to provide bias voltage to the aiding unit, wherein the aiding unit is configured to avoid dead lock of the input pair.

BRIEF DESCRIPTION OF THE DRAWINGS

Non-limiting and non-exhaustive embodiments of the present invention are described with reference to the follow-

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ing figures, wherein like reference numerals refer to like parts throughout the various views unless otherwise specified.

FIG. 1 is a diagram illustrating an embodiment of an operational amplifier.

FIG. 2 is a diagram illustrating another embodiment of an operational amplifier.

FIG. 3 is a diagram illustrating a specific implementation of the operational amplifier shown in FIG. 2.

FIG. 4 is a diagram illustrating another specific implementation of the operational amplifier shown in FIG. 2.

FIG. 5 is a diagram illustrating another specific implementation of the operational amplifier shown in FIG. 2.

FIG. 6 is a diagram illustrating another specific implementation of the operational amplifier shown in FIG. 2.

FIG. 7 is a flow chart of a method of amplifying in the operational amplifier.

FIG. 8 is a diagram illustrating the connection relationship of an operational amplifier.

DETAILED DESCRIPTION OF THE ILLUSTRATED EMBODIMENTS

Various aspects and examples of the invention will now be described. The following description provides specific details for a thorough understanding and enabling description of these examples. Those skilled in the art will understand, however, that the invention may be practiced without many of these details. Additionally, some well-known structures or functions may not be shown or described in detail, so as to avoid unnecessarily obscuring the relevant description.

FIG. 1 is a diagram illustrating an embodiment of an operational amplifier 10. The operational amplifier 10 comprises an input pair 100, an aiding unit 110, an even number of amplification stages 120, a feeding unit 130, a first current source 140 and a second current source 150. Both the input pair 100 and the aiding unit 110 are connected to the first current source 140. The input pair 100 is also configured to receive differential input voltage. Both the input pair 100 and the aiding unit 110 are further connected to a first stage of the even number of amplification stages 120. Note that the operational amplifier includes multiple amplification stages, the number of multiple amplification stages is even. The even number of amplification stages 120 are connected in series, and a last stage of the amplification stages 120 is configured to output differential output voltages. The amplification stages are connected in series means an input of next amplification stage is connected to an output of previous amplification stage. The feeding unit 130 is configured to receive a common mode voltage of the differential output voltages from the last stage of the even number of amplification stages 120. The feeding unit 130 is configured to feed a voltage on a first node of the feeding unit 130 back to the aiding unit 110 so as to provide bias voltage to the aiding unit 110, wherein the aiding unit 110 is configured to avoid dead lock of the input pair 100.

FIG. 2 is a diagram illustrating another embodiment of an operational amplifier 20. As shown in FIG. 2, the common mode voltage of the differential output voltages comprises a median voltage potential between the differential output voltages voutp and voutn, that is the connecting point of the resistor R1 and the resistor R2. The resistance of R1 equals the resistance of R2. The input pair 200 shown in the dashed block comprises a first MOS transistor M₁ and a second MOS transistor M₂. The aiding unit 210 shown in the dashed block comprises a third MOS transistor M₃ and a fourth MOS transistor M₄. The second current source comprises a fifth MOS transistor M₅. The feeding unit 230 comprises a seventh MOS

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transistor M_7 and an eight MOS transistor M_8 . The even number of amplification stages **220** comprises a first amplification stage **2210** and a second amplification stage **2220**. The first amplification stage **2210** may also comprise the input pair **200**. The operational amplifier further comprises a sixth MOS transistor M_6 .

First nodes of both the first MOS transistor M_1 and the second MOS transistor M_2 are connected to the first current source **I0**. Second node of the first MOS transistor M_1 is configured to receive a positive input voltage v_{inp} , and a second node of the second MOS transistor M_2 is configured to receive a negative input voltage v_{inn} . A third node of the first MOS transistor M_1 is connected to a third node of the third MOS transistor M_3 . A third node of the second MOS transistor M_2 is connected to a third node of the fourth MOS transistor M_4 .

First nodes of both the third MOS transistor M_3 and the fourth MOS transistor M_4 are connected to the first current source **I0**, just as the first nodes of both the first MOS transistor M_1 and second MOS transistor M_2 . Second nodes of both the third MOS transistor M_3 and the fourth MOS transistor M_4 are connected to a third node of the seventh MOS transistor M_7 . The third node of the third MOS transistor M_3 is also connected to a first port of the first amplification stage **2210**. The third node of the fourth MOS transistor M_4 is also connected to a second port of the first amplification stage **2210**.

A first node of the fifth MOS transistor M_5 is connected to a first power supply. A second node of the fifth MOS transistor M_5 is connected to a third port of the first amplification stage **2210**. A third node of the fifth MOS transistor M_5 is connected to a third node of the seventh MOS transistor M_7 .

A first node of the seventh MOS transistor M_7 is connected to both a first node of the eighth MOS transistor M_8 and a third node of the sixth MOS transistor M_6 . A second node of the seventh MOS transistor M_7 is connected to a connection point of the first resistor R_1 and the second resistor R_2 . A second node of the eighth MOS transistor M_8 is connected to a fifth voltage source **V5**. The fifth voltage source **V5** may be connected to ground. A third node of the eighth MOS transistor M_8 is connected to the first nodes of the first and the second MOS transistors M_1 and M_2 .

A third port of the first amplification stage **2210** is connected to a third voltage source **V3**, and the third voltage source **V3** is connected to the first power supply. Fourth port of the first amplification stage **2210** is connected to a fourth voltage source **V4**, and the fourth voltage source **V4** is connected to ground. A fifth port of the first amplification stage **2210** is connected to a first port of the second amplification stage **2220**. A sixth port of the first amplification stage **2210** is connected to a second port of the second amplification stage **2220**. A seventh port of the first amplification stage is connected to a sixth port of the first amplification stage. An eighth port of the first amplification stage is connected to a first voltage source **V1**, a third port of the second amplification stage is configured to output a positive output voltage, a third a fourth port of the second amplification stage is configured to output a negative output voltage, wherein a first resistor and a second resistor are connected in serial between a positive output voltage port and a negative output voltage port. V_{ref} is the reference voltage, which can be provided by the fifth voltage source **V5**. V_A is the voltage of the drain of the fifth MOS transistor M_5 .

FIG. 3 is a diagram illustrating a specific implementation of the operational amplifier shown in FIG. 2. As shown in FIG. 3, the first amplification stage **3210** comprises a ninth MOS transistor M_9 , a tenth MOS transistor M_{10} , an eleventh

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MOS transistor M_{11} , a twelfth MOS transistor M_{12} , a thirteenth MOS transistor M_{13} , a fourteenth MOS transistor M_{14} . The first port of the first amplification stage **3210** comprises a first node of the eleventh MOS transistor M_{11} . The second port of the first amplification stage **3210** comprises a first node of the twelfth MOS transistor M_{12} . The third port of the first amplification stage **3210** comprises a second node of the tenth MOS transistor M_{10} . The fourth port of the first amplification stage **3210** comprises a second node of the thirteenth MOS transistor M_{13} . The fifth port of the first amplification stage **3210** comprises a third node of the twelfth MOS transistor M_{12} . The sixth port of the first amplification stage **3210** comprises a third node of the eleventh MOS transistor M_{11} . The seventh port of the first amplification stage **3210** comprises a second node of the fourteenth MOS transistor M_{14} . The eighth port of the first amplification stage comprises a second node of the eleventh MOS transistor M_{11} .

First nodes of both the ninth and tenth MOS transistors M_9 and M_{10} are connected to the first power supply. Second nodes of both the ninth and tenth MOS transistors M_9 and M_{10} are connected to both a third voltage source **V3** and the second node of the fifth MOS transistor M_5 . A third node of the ninth MOS transistor M_9 is connected to a third node of the eleventh MOS transistor M_{11} . A third node of the tenth MOS transistor M_{10} is connected to a third node of the twelfth MOS transistor M_{12} .

A first node of the eleventh MOS transistor M_{11} is connected to a third node of the thirteenth MOS transistor M_{13} . A first node of the twelfth MOS transistor M_{12} is connected to a third node of the fourteenth MOS transistor M_{14} . Second nodes of both the eleventh and twelfth MOS transistors M_{11} and M_{12} are connected to the first voltage source.

Both first nodes of the thirteenth MOS transistor M_{13} and the fourteenth MOS transistor M_{14} are connected to a second power supply. Both second nodes of the thirteenth MOS transistor M_{13} and the fourteenth MOS transistor M_{14} are connected to the fourth voltage source **V4**.

The second amplification stage **3220** comprises a seventeenth MOS transistor M_{17} , an eighteenth MOS transistor M_{18} , a nineteenth MOS transistor M_{19} , and a twentieth MOS transistor M_{20} .

The first port of the second amplification stage **3220** comprises a second node of the seventeenth MOS transistor M_{17} . The second port of the second amplification stage **3220** comprises a second node of the eighteenth MOS transistor M_{18} . The third port of the second amplification stage **3220** comprises a third node of the seventeenth MOS transistor M_{17} . The fourth port of the second amplification stage **3220** comprises a third node of the eighteenth MOS transistor M_{18} . The fifth port of the second amplification stage **3220** comprises a second node of the twentieth MOS transistor M_{20} . The sixth port of the second amplification stage **3220** comprises a second node of the nineteenth MOS transistor M_{19} .

First nodes of both the seventeenth and eighteenth MOS transistors M_{17} and M_{18} are connected to the first power supply. A second node of the seventeenth MOS transistor M_{17} is connected to the third node of the twelfth MOS transistor M_{12} . A second node of the eighteenth MOS transistor M_{18} is connected to the third node of the eleventh MOS transistor M_{11} . A third node of the seventeenth MOS transistor M_{17} is connected to a third node of the nineteenth MOS transistor M_{19} . A third node of the eighteenth MOS transistor M_{18} is connected to a third node of the twentieth MOS transistor M_{20} .

First nodes of both the nineteenth MOS transistor M_{19} and the twentieth MOS transistor M_{20} are connected to the second

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power supply. Second nodes of both the nineteenth and twentieth MOS transistors M_{19} and M_{20} are connected to the fourth voltage source.

FIG. 4 is a diagram illustrating another specific implementation of the operational amplifier shown in FIG. 2. FIG. 4 has many elements similar to that in FIG. 3. Therefore details are omitted for elements already described with respect to FIG. 3. As shown in FIG. 4, the first amplification stage **4210** further comprises a fifteenth MOS transistor M_{15} and a sixteenth MOS transistor M_{16} . The ninth MOS transistor M_9 is connected to the eleventh MOS transistor M_{11} via the fifteenth MOS transistor M_{15} . The tenth MOS transistor M_{10} is connected to the twelfth MOS transistor M_{12} via the sixteenth MOS transistor M_{16} . The fifteenth MOS transistor M_{15} and the sixteenth MOS transistor M_{16} are cascaded, so as to improve the output impedance, then the higher DC gain can be achieved.

First node of the fifteenth MOS transistor M_{15} is connected to third node of the ninth MOS transistor M_9 . First node of the sixteenth MOS transistor M_{16} is connected to the third node of the tenth MOS transistor M_{10} . Second nodes of both the fifteenth MOS transistor M_{15} and the sixteenth MOS transistor M_{16} are connected to the second voltage source V_2 . A third node of the fifteenth MOS transistor M_{15} is connected to the third node of the eleventh MOS transistor M_{11} . A third node of the sixteenth MOS transistor M_{16} is connected to the third node of the twelfth MOS transistor M_{12} .

In the embodiments shown in FIG. 3 or FIG. 4, the first, the second, the third, the fourth MOS transistors M_1 , M_2 , M_3 and M_4 , the fifth MOS transistor M_5 , the ninth MOS transistor M_9 , the tenth MOS transistor M_{10} , the seventeenth MOS transistor M_{17} and the eighteenth MOS transistor M_{18} include PMOS transistors. The sixth MOS transistor M_6 , the seventh MOS transistor M_7 , the eighth MOS transistor M_8 , the eleventh MOS transistor M_{11} , the twelfth MOS transistor M_{12} , the thirteenth MOS transistor M_{13} , the fourteenth MOS transistor M_{14} , the nineteenth MOS transistor M_{19} and the twentieth MOS transistor M_{20} include NMOS transistors. The first power supply comprises a positive power supply (vdd) and the second power supply comprises ground (gnd).

The first node of each of these MOS transistors comprises a source, the second node of each of these MOS transistors comprises a gate, and the third node of each of these MOS transistors comprises a drain.

Referring again to FIG. 4, the fifteenth MOS transistor M_{15} and the sixteenth MOS transistor M_{16} comprise PMOS transistors. The first node of each of the fifteenth and sixteenth MOS transistors M_{15} , M_{16} comprises a source, the second node of each of the fifteenth and sixteenth MOS transistors M_{15} and M_{16} comprises a gate. The third node of each of the fifteenth and sixteenth MOS transistors M_{15} and M_{16} comprises a drain.

FIG. 5 is a diagram illustrating another specific implementation of the operational amplifier shown in FIG. 2. The difference between FIG. 3 and FIG. 5 lies in that FIG. 5 uses inverted components with respect to FIG. 3. For example, the first MOS transistor M_1 in FIG. 3 is a PMOS transistor, while the first MOS transistor M_1 in FIG. 5 is a NMOS transistor instead.

Referring to FIG. 5, the first amplification stage **5210** and the second amplification stage **5220** include similar elements as the first amplification stage **3210** and the second amplification stage **3220** shown in FIG. 3. Therefore details are omitted for elements already described with respect to FIG. 5. The first, the second, the third, the fourth MOS transistors M_1 , M_2 , M_3 and M_4 , the fifth MOS transistor M_5 , the ninth MOS transistor M_9 , the tenth MOS transistor M_{10} , the seventeenth

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MOS transistor M_{17} , the eighteenth MOS transistor M_{18} include NMOS transistors. The sixth MOS transistor M_6 , the seventh MOS transistor M_7 , the eighth MOS transistor M_8 , the eleventh MOS transistor M_{11} , the twelfth MOS transistor M_{12} , the thirteenth MOS transistor M_{13} , the fourteenth MOS transistor M_{14} , the nineteenth MOS transistor M_{19} and the twentieth MOS transistor M_{20} include PMOS transistors. The first power supply comprises ground supply (gnd) and the second power supply comprises a positive power (vdd).

The first node of each of these MOS transistors comprises a source. The second node of each of these MOS transistors comprises a gate. The third node of each of these MOS transistors comprises a drain.

FIG. 6 is a diagram illustrating another specific implementation of the operational amplifier shown in FIG. 2. FIG. 6 has many elements similar to that in FIG. 5. Therefore details are omitted for elements already described with respect to FIG. 5. In FIG. 6, the first amplification stage **6210** further comprises a fifteenth MOS transistor M_{15} and a sixteenth MOS transistor M_{16} . The ninth MOS transistor M_9 is connected to the eleventh MOS transistor M_{11} via the fifteenth MOS transistor M_{15} , and the tenth MOS transistor M_{10} is connected to the twelfth MOS transistor M_{12} via the sixteenth MOS transistor M_{16} .

First node of the fifteenth MOS transistor **M15** is connected to third node of the ninth MOS transistor **M9**. First node of the sixteenth MOS transistor **M16** is connected to the third node of the tenth MOS transistor **M10**. Second nodes of both the fifteenth MOS transistor **M15** and the sixteenth MOS transistor **M16** are connected to the second voltage source V_2 , and V_2 is connected to a first power supply. A third node of the fifteenth MOS transistor **M15** is connected to the third node of the eleventh MOS transistor **M11**. A third node of the sixteenth MOS transistor **M16** is connected to the third node of the twelfth MOS transistor **M12**.

The fifteenth MOS transistor **M15** and the sixteenth MOS transistor **M16** comprise NMOS transistors. The first node of each of the fifteenth and sixteenth MOS transistors **M15** and **M16** comprises a source. The second node of each of the fifteenth and sixteenth MOS transistors **M15** and **M16** comprises a gate. The third node of each of the fifteenth and sixteenth MOS transistors **M15** and **M16** comprises a drain.

FIG. 7 is a flow chart of a method **70** of amplifying in the operational amplifier. The method **70** can be implemented in an operational amplifier, for example, the operational amplifier **10** shown in FIG. 1.

First nodes of both the input pair **100** and the aiding unit **110** are connected to the first current source **140**. Third nodes of both the input pair **100** and the aiding unit **110** are connected to a first stage of the even number of amplification stages **120**. The even number of amplification stages **120** are connected in series. The feeding unit **130** is configured to receive a common mode voltage of the differential output voltages.

The method **70** comprises receiving (in block **700**), by the input pair **100**, differential input voltage; amplifying (in block **710**) the differential input voltage by the even number of amplification stages; outputting (in block **720**), by a last stage of the amplification stages, differential output voltages; feeding (in block **730**), by the feeding unit, a voltage on a first node of the feeding unit back to the aiding unit so as to provide bias voltage to the aiding unit, wherein the aiding unit is configured to avoid dead lock of the input pair.

FIG. 8 is a diagram illustrating the connection relationship of an operational amplifier **80**. The positive input port (vinp) of the operational amplifier **80** is connected to the negative output port (voutn) of the operational amplifier **80**, and the

negative input port (vinn) of the operational amplifier 80 is connected to the positive output port (voutp) of the operational amplifier 80.

During operation, suppose the operational amplifier works in buffer mode, that means $v_{inp}=v_{inn}$, and outputs of the operational amplifier are fed back to input port of the operational amplifier, that means $v_{inp}=v_{inn}=v_{outp}=v_{outn}$, which is shown in FIG. 8. In some circumstances, it may happen that $v_{outp}=v_{outn}=v_{dd}$, therefore $v_{inp}=v_{inn}=v_{dd}$. Then the common mode feedback circuit can avoid the deadlock on vdd, which is discussed below.

With embodiments of the invention, for example, the embodiment shown in FIG. 2, when $v_{inp}=v_{inn}=v_{dd}$, the first PMOS transistor M_1 and the second PMOS transistor M_2 are off. As the gates of PMOS transistors M_3 and M_4 are configured to receive voltage VA, the voltage VA is considered. VA is the voltage of the drain of the fifth PMOS transistor M_5 . As $v_{outp}=v_{outn}=v_{dd}$ which is higher than v_{ref} , most of the current through the NMOS M_6 passes through NMOS transistor M_7 instead of the NMOS transistor M_8 , that is $I_7>I_8$. V_{ref} is the reference voltage, which can be provided by the fifth voltage source V5. As $I_6=I_7+I_8$, and $I_5=I_7$, therefore $I_6>I_5$ and the voltage VA decreases and is lower than Vdd. Therefore the PMOS transistors M_3 and M_4 are on. I_5 represents the current passing through the MOS transistor M_5 , I_6 represents the current passing through the MOS transistor M_6 , I_7 represents the current passing through the MOS transistor M_7 , I_8 represents the current passing through the MOS transistor M_8 .

As the first current source I0 is fed to both the input pair including the PMOS transistor pair M_1 and M_2 , and the aiding unit including the PMOS transistor pair M_3 and M_4 , and M_3 and M_4 are on, the current I0 from the first current source can pass through the PMOS transistor pair M_3 and M_4 , and the deadlock can be solved.

On the other hand, during normal operation, that is, the first and second PMOS transistors M_1 and M_2 work at common mode with $V_{inn}=V_{inp}=V_{ref}<v_{dd}$. V_{ref} may be at a desirable operating voltage. Further the operational amplifier 20 operates to amplify, and works under common mode balance, that means $V_{inn}=V_{inp}=V_{ref}$. The fifth MOS transistor M_5 is on. $V_{outp}=V_{outn}=V_{ref}$. $I_5>I_7=I_8=\frac{1}{2}I_6$. When the voltage of VA is relatively low, the fifth MOS transistor M_5 is saturated, and its current is larger than $\frac{1}{2}I_6$, therefore VA rises, which forces M_5 to linear region, and I_5 decreases until $I_5=\frac{1}{2}I_6$. Therefore VA approximately equals Vdd, that is, $VA\approx V_{dd}$. Therefore the PMOS transistors M_3 and M_4 are off, and only the input pair M_1 and M_2 work, so as not to influence the normal operational of the PMOS transistors M_1 and M_2 .

In some embodiments, the aiding unit 210 does not need additional biasing voltage, and it uses an inherent voltage point in the operational amplifier itself, therefore the operational amplifier can save power. Further, the aiding unit 210 will not cause additional noises. The aiding unit will not bypass current, which can guarantee the transconductance of the input pair. Since when VA rises to be approximate to vdd, the third MOS transistor M_3 and the fourth MOS transistor M_4 are cut off, and no current passes through these transistors. Further, if the sizes of the devices are fixed, transconductance is proportional to current. The larger the current, the larger the transconductance. When the third MOS transistor M_3 and the fourth MOS transistor M_4 are cut off, and no current passes through these transistors, the current passing through the input pair will not change, therefore the transconductance of the input pair maintains.

Although the present invention has been described with reference to specific exemplary embodiments, the present invention is not limited to the embodiments described herein,

and it can be implemented in form of modifications or alterations without deviating from the spirit and scope of the appended claims. Accordingly, the description and the drawings are to be regarded in an illustrative rather than a restrictive sense.

From the foregoing, it will be appreciated that specific embodiments of the technology have been described herein for purposes of illustration, however various modifications can be made without deviating from the spirit and scope of the present invention. Accordingly, the present invention is not restricted except in the spirit of the appended claims.

Other variations to the disclosed embodiments can be understood and effected by those skilled in the art in practicing the claimed invention, from a study of the drawings, the disclosure, and the appended claims. In the claims the word "comprising" does not exclude other elements or steps, and the indefinite article "a" or "an" does not exclude a plurality. Even if particular features are recited in different dependent claims, the present invention also relates to the embodiments including all these features. Any reference signs in the claims should not be construed as limiting the scope.

Features and aspects of various embodiments may be integrated into other embodiments, and embodiments illustrated in this document may be implemented without all of the features or aspects illustrated or described. One skilled in the art will appreciate that although specific examples and embodiments of the system and methods have been described for purposes of illustration, various modifications can be made without deviating from the spirit and scope of the present invention. Moreover, features of one embodiment may be incorporated into other embodiments, even where those features are not described together in a single embodiment within the present document. Accordingly, the invention is described by the appended claims.

What is claimed is:

1. An operational amplifier comprising:

an input pair, an aiding unit, an even number of amplification stages, a feeding unit, a first current source, a second current source; wherein

both the input pair and the aiding unit are connected to the first current source, the input pair is also configured to receive differential input voltage, and both the input pair and the aiding unit are further connected to a first stage of the even number of amplification stages;

the even number of amplification stages are connected in series, and a last stage of the amplification stages is configured to output differential output voltages;

the feeding unit is configured to receive a common mode voltage of the differential output voltages from the last stage, and is configured to feed a voltage on a first node of the feeding unit back to the aiding unit so as to provide bias voltage to the aiding unit, wherein the aiding unit is configured to avoid dead lock of the input pair.

2. The operational amplifier of claim 1, wherein the common mode voltage of the differential output voltages comprises a median voltage potential between the differential output voltages.

3. The operational amplifier of claim 1, wherein the input pair comprises a first MOS transistor and a second MOS transistor, the aiding unit comprises a third MOS transistor and a fourth MOS transistor, the second current source comprises a fifth MOS transistor, the feeding unit comprises a seventh MOS transistor and an eighth MOS transistor, the even number of amplification stages comprises a first amplification stage and a second amplification stage, the operational amplifier further comprises a sixth MOS transistor;

wherein first nodes of both the first MOS transistor and the second MOS transistor are connected to the first current source, second node of the first MOS transistor is configured to receive a positive input voltage, and a second node of the second MOS transistor is configured to receive a negative input voltage, a third node of the first MOS transistor is connected to a third node of the third MOS transistor, a third node of the second MOS transistor is connected to a third node of the fourth MOS transistor;

first nodes of both the third MOS transistor and the fourth MOS transistor are connected to the first current source, second nodes of both the third MOS transistor and the fourth MOS transistor are connected to a third node of the seventh MOS transistor, the third node of the third MOS transistor is also connected to a first port of the first amplification stage, the third node of the fourth MOS transistor is also connected to a second port of the first amplification stage;

a first node of the fifth MOS transistor is connected to a first power supply, a second node of the fifth MOS transistor is connected to a third port of the first amplification stage, a third node of the fifth MOS transistor is connected to a third node of the seventh MOS transistor;

a first node of the seventh MOS transistor is connected to both a first node of the eighth MOS transistor and a third node of the sixth MOS transistor, a second node of the seventh MOS transistor is connected to a connection point of the first resistor and the second resistor, a second node of the eighth MOS transistor is connected to a fifth voltage source, a third node of the eighth MOS transistor is connected to the first nodes of the first and the second MOS transistors.

4. The operational amplifier of claim 3, wherein

A third port of the first amplification stage is connected to a third voltage source, fourth and seventh ports of the first amplification stage are connected to a fourth voltage source, a fifth port of the first amplification stage is connected to a first port of the second amplification stage, a sixth port of the first amplification stage is connected to a second port of the second amplification stage, an eighth port of the first amplification stage is connected to a first voltage source, a third port of the second amplification stage is configured to output a positive output voltage, a third a fourth port of the second amplification stage is configured to output a negative output voltage, wherein a first resistor and a second resistor are connected in serial between a positive output voltage port and a negative output voltage port.

5. The operational amplifier of claim 4, wherein

the first amplification stage comprises a ninth MOS transistor, a tenth MOS transistor, an eleventh MOS transistor, a twelfth MOS transistor, a thirteenth MOS transistor, a fourteenth MOS transistor,

wherein the first port of the first amplification stage comprises a first node of the eleventh MOS transistor, the second port of the first amplification stage comprises a first node of the twelfth MOS transistor, the third port of the first amplification stage comprises a second node of the tenth MOS transistor, the fourth port of the first amplification stage comprises a second node of the thirteenth MOS transistor, the fifth port of the first amplification stage comprises a third node of the twelfth MOS transistor, the sixth port of the first amplification stage comprises a third node of the eleventh MOS transistor, the seventh port of the first amplification stage comprises a second node of the fourteenth MOS transistor;

the eighth port of the first amplification stage comprises a second node of the eleventh MOS transistor;

wherein first nodes of both the ninth and tenth MOS transistors are connected to the first power supply, second nodes of both the ninth and tenth MOS transistors are connected to the second node of the fifth MOS transistor, a third node of the ninth MOS transistor is connected to a third node of the eleventh MOS transistor, a third node of the tenth MOS transistor is connected to a third node of the twelfth MOS transistor;

a first node of the eleventh MOS transistor is connected to a third node of the thirteenth MOS transistor, a first node of the twelfth MOS transistor is connected to a third node of the fourteenth MOS transistor, second nodes of both the eleventh and twelfth MOS transistors are connected to the first voltage source; and

both first nodes of the thirteenth MOS transistor and the fourteenth MOS transistor are connected to a second power supply, both second nodes of the thirteenth MOS transistor and the fourteenth MOS transistor are connected to the fourth voltage source.

6. The operational amplifier of claim 5, wherein the first amplification stage further comprises a fifteenth MOS transistor and a sixteenth MOS transistor, wherein the ninth MOS transistor is connected to the eleventh MOS transistor via the fifteenth MOS transistor, and the tenth MOS transistor is connected to the twelfth MOS transistor via the sixteenth MOS transistor;

first node of the fifteenth MOS transistor is connected to third node of the ninth MOS transistor, first node of the sixteenth MOS transistor is connected to the third node of the tenth MOS transistor, second nodes of both the fifteenth MOS transistor and the sixteenth MOS transistor are connected to the second voltage source, a third node of the fifteenth MOS transistor is connected to the third node of the eleventh MOS transistor, a third node of the sixteenth MOS transistor is connected to the third node of the twelfth MOS transistor.

7. The operational amplifier of claim 5, wherein the second amplification stage comprises a seventeenth MOS transistor, an eighteenth MOS transistor, a nineteenth MOS transistor, a twentieth MOS transistor, wherein the first port of the second amplification stage comprises a second node of the seventeenth MOS transistor, the second port of the second amplification stage comprises a second node of the eighteenth MOS transistor, the third port of the second amplification stage comprises a third node of the seventeenth MOS transistor, the fourth port of the second amplification stage comprises a third node of the eighteenth MOS transistor, the fifth port of the second amplification stage comprises a second node of the twentieth MOS transistor, the sixth port of the second amplification stage comprises a second node of the nineteenth MOS transistor;

wherein first nodes of both the seventeenth and eighteenth MOS transistors are connected to the first power supply, a second node of the seventeenth MOS transistor is connected to the third node of the twelfth MOS transistor, a second node of the eighteenth MOS transistor is connected to the third node of the eleventh MOS transistor, a third node of the seventeenth MOS transistor is connected to a third node of the nineteenth MOS transistor, a third node of the eighteenth MOS transistor is connected to a third node of the twentieth MOS transistor;

first nodes of both the nineteenth MOS transistor and the twentieth MOS transistor are connected to a second

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power supply, second nodes of both the nineteenth and twentieth MOS transistors are connected to the fourth voltage source.

8. The operational amplifier of claim 7, wherein the first, the second, the third, the fourth MOS transistors, the fifth MOS transistor, the ninth MOS transistor, the tenth MOS transistor, the seventeenth MOS transistor and the eighteenth MOS transistor include PMOS transistors, the sixth MOS transistor, the seventh MOS transistor, the eighth MOS transistor, the eleventh MOS transistor, the twelfth MOS transistor, the thirteenth MOS transistor, the fourteenth MOS transistor, the nineteenth MOS transistor and the twentieth MOS transistor include NMOS transistors, the first power supply comprises a positive power supply and the second power supply comprises ground; and

the first node of each of these MOS transistors comprises a source, the second node of each of these MOS transistors comprises a gate, and the third node of each of these MOS transistors comprises a drain.

9. The operational amplifier of claim 8, wherein the first amplification stage further comprises a fifteenth MOS transistor and a sixteenth MOS transistor, wherein the ninth MOS transistor is connected to the eleventh MOS transistor via the fifteenth MOS transistor, and the tenth MOS transistor is connected to the twelfth MOS transistor via the sixteenth MOS transistor;

first node of the fifteenth MOS transistor is connected to third node of the ninth MOS transistor, second node of the sixteenth MOS transistor is connected to the third node of the tenth MOS transistor, second nodes of both the fifteenth MOS transistor and the sixteenth MOS transistor are connected to the second voltage source, a third node of the fifteenth MOS transistor is connected to the third node of the eleventh MOS transistor, a third node of the sixteenth MOS transistor is connected to the third node of the twelfth MOS transistor; and

the fifteenth MOS transistor and the sixteenth MOS transistor comprise PMOS transistors, and the first node of each of the fifteenth and sixteenth MOS transistors comprises a source, the second node of each of the fifteenth and sixteenth MOS transistors comprises a gate, and the third node of each of the fifteenth and sixteenth MOS transistors comprises a drain.

10. The operational amplifier of claim 7, wherein the first, the second, the third, the fourth MOS transistors, the fifth MOS transistor, the ninth MOS transistor, the tenth MOS transistor, the seventeenth MOS transistor, the eighteenth MOS transistor include NMOS transistors, the sixth MOS transistor, the seventh MOS transistor, the eighth MOS transistor, the eleventh MOS transistor, the twelfth MOS transistor, the thirteenth MOS transistor, the fourteenth MOS transistor, the nineteenth MOS transistor and the twentieth MOS transistor include PMOS transistors, the first power supply comprises ground supply and the second power supply comprises a positive power; and

the first node of each of these MOS transistors comprises a source, the second node of each of these MOS transistors comprises a gate, and the third node of each of these MOS transistors comprises a drain.

11. The operational amplifier of claim 10, wherein the first amplification stage further comprises a fifteenth MOS transistor and a sixteenth MOS transistor, wherein the ninth MOS transistor is connected to the eleventh MOS transistor via the fifteenth MOS transistor, and the tenth MOS transistor is connected to the twelfth MOS transistor via the sixteenth MOS transistor;

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first node of the fifteenth MOS transistor is connected to third node of the ninth MOS transistor, first node of the sixteenth MOS transistor is connected to the third node of the tenth MOS transistor, second nodes of both the fifteenth MOS transistor and the sixteenth MOS transistor are connected to the second voltage source, a third node of the fifteenth MOS transistor is connected to the third node of the eleventh MOS transistor, a third node of the sixteenth MOS transistor is connected to the third node of the twelfth MOS transistor; and

the fifteenth MOS transistor and the sixteenth MOS transistor comprise NMOS transistors, and the first node of each of the fifteenth and sixteenth MOS transistors comprises a source, the second node of each of the fifteenth and sixteenth MOS transistors comprises a gate, and the third node of each of the fifteenth and sixteenth MOS transistors comprises a drain.

12. A method in an operational amplifier, wherein the operational amplifier comprises:

an input pair, an aiding unit, an even number of amplification stages, a feeding unit, a first current source, a second current source; wherein

first nodes of both the input pair and the aiding unit are connected to the first current source, and third nodes of both the input pair and the aiding unit are connected to a first stage of the even number of amplification stages; the even number of amplification stages are connected in series;

the feeding unit is configured to receive a common mode voltage of the differential output voltages from a last stage of the amplification stages;

where the method comprises

receiving, by the input pair, differential input voltage;

amplifying the differential input voltage by the even number of amplification stages;

outputting, by a last stage of the amplification stages, differential output voltages;

feeding, by the feeding unit, a voltage on a first node of the feeding unit back to the aiding unit so as to provide bias voltage to the aiding unit, wherein the aiding unit is configured to avoid dead lock of the input pair.

13. The method of claim 12, wherein the common mode voltage of the differential output voltages has a median value between the differential output voltages.

14. The method of claim 12, wherein the input pair comprises a first MOS transistor and a second MOS transistor, the aiding unit comprises a third MOS transistor and a fourth MOS transistor, the second current source comprises a fifth MOS transistor, the feeding unit comprises a seventh MOS transistor and an eighth MOS transistor, the even number of amplification stages comprises a first amplification stage and a second amplification stage, the operational amplifier further comprises a sixth MOS transistor;

wherein first nodes of both the first MOS transistor and the second MOS transistor are connected to the first current source, second nodes of the first MOS transistor and a second node of the second MOS transistor are respectively configured to receive a positive input voltage and a negative input voltage, a third node of the first MOS transistor is connected to a third node of the third MOS transistor, a third node of the second MOS transistor is connected to a third node of the fourth MOS transistor; first nodes of both the third MOS transistor and the fourth MOS transistor are connected to the first current source, second nodes of both the third MOS transistor and the fourth MOS transistor are connected to a third node of the seventh MOS transistor, the third node of the third

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MOS transistor is also connected to a first port of the first amplification stage, the third node of the fourth MOS transistor is also connected to a second port of the first amplification stage;

- a first node of the fifth MOS transistor is connected to a first power supply, a second node of the fifth MOS transistor is connected to the third port of the first amplification stage, a third node of the fifth MOS transistor is connected to a third node of the seventh MOS transistor;
- a first node of the seventh MOS transistor is connected to both a first node of the eighth MOS transistor and a third node of the sixth MOS transistor, a second node of the seventh MOS transistor is connected to a connection point of the first resistor and the second resistor, a second node of the eighth MOS transistor is connected to a fifth voltage source, a third node of the eighth MOS transistor is connected to the first nodes of the first and the second MOS transistors.

15. The method of claim **14**, wherein

- a third port of the first amplification stage is connected to a third voltage source, fourth and seventh ports of the first amplification stage are connected to a fourth voltage source, a fifth port of the first amplification stage is connected to a first port of the second amplification stage, a sixth port of the first amplification stage is connected to a second port of the second amplification stage, an eighth port of the first amplification stage is connected to a first voltage source, a third port of the second amplification stage is configured to output a positive output voltage, a third a fourth port of the second amplification stage is configured to output a negative output voltage, wherein a first resistor and a second resistor are connected in serial between a positive output voltage port and a negative output voltage port.

16. The method of claim **15**, wherein

- the first amplification stage comprises a ninth MOS transistor, a tenth MOS transistor, an eleventh MOS transistor, a twelfth MOS transistor, a thirteenth MOS transistor, a fourteenth MOS transistor,

wherein the first port of the first amplification stage comprises a first node of the eleventh MOS transistor, the second port of the first amplification stage comprises a first node of the twelfth MOS transistor, the third port of the first amplification stage comprises a second node of the tenth MOS transistor, the fourth port of the first amplification stage comprises a second node of the thirteenth MOS transistor, the fifth port of the first amplification stage comprises a third node of the twelfth MOS transistor, the sixth port of the first amplification stage comprises a third node of the eleventh MOS transistor, the seventh port of the first amplification stage comprises a second node of the fourteenth MOS transistor; the eighth port of the first amplification stage comprises a second node of the eleventh MOS transistor;

wherein first nodes of both the ninth and tenth MOS transistors are connected to the first power supply, second nodes of both the ninth and tenth MOS transistors are connected to the second node of the fifth MOS transistor, a third node of the ninth MOS transistor is connected to a third node of the eleventh MOS transistor, a third node of the tenth MOS transistor is connected to a third node of the twelfth MOS transistor;

- a first node of the eleventh MOS transistor is connected to a third node of the thirteenth MOS transistor, a first node of the twelfth MOS transistor is connected to a third node of the fourteenth MOS transistor, second nodes of

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both the eleventh and twelfth MOS transistors are connected to the first voltage source; and

both first nodes of the thirteenth MOS transistor and the fourteenth MOS transistor are connected to a second power supply, both second nodes of the thirteenth MOS transistor and the fourteenth MOS transistor are connected to the fourth voltage source.

17. The method of claim **16** wherein

the first amplification stage further comprises a fifteenth MOS transistor and a sixteenth MOS transistor, wherein the ninth MOS transistor is connected to the eleventh MOS transistor via the fifteenth MOS transistor, and the tenth MOS transistor is connected to the twelfth MOS transistor via the sixteenth MOS transistor;

first node of the fifteenth MOS transistor is connected to third node of the ninth MOS transistor, first node of the sixteenth MOS transistor is connected to the third node of the tenth MOS transistor, second nodes of both the fifteenth MOS transistor and the sixteenth MOS transistor are connected to the second voltage source, a third node of the fifteenth MOS transistor is connected to the third node of the eleventh MOS transistor, a third node of the sixteenth MOS transistor is connected to the third node of the twelfth MOS transistor.

18. The method of claim **16**, wherein

the second amplification stage comprises a seventeenth MOS transistor, an eighteenth MOS transistor, a nineteenth MOS transistor, a twentieth MOS transistor,

wherein the first port of the second amplification stage comprises a second node of the seventeenth MOS transistor, the second port of the second amplification stage comprises a second node of the eighteenth MOS transistor, the third port of the second amplification stage comprises a third node of the seventeenth MOS transistor, the fourth port of the second amplification stage comprises a third node of the eighteenth MOS transistor, the fifth port of the second amplification stage comprises a second node of the twentieth MOS transistor, the sixth port of the second amplification stage comprises a second node of the nineteenth MOS transistor;

wherein first nodes of both the seventeenth and eighteenth MOS transistors are connected to the first power supply, a second node of the seventeenth MOS transistor is connected to the third node of the twelfth MOS transistor, a second node of the eighteenth MOS transistor is connected to the third node of the eleventh MOS transistor, a third node of the seventeenth MOS transistor is connected to a third node of the nineteenth MOS transistor, a third node of the eighteenth MOS transistor is connected to a third node of the twentieth MOS transistor;

first nodes of both the nineteenth MOS transistor and the twentieth MOS transistor are connected to a second power supply, second nodes of both the nineteenth and twentieth MOS transistors are connected to the fourth voltage source.

19. The method of claim **18**, wherein the first, the second, the third, the fourth MOS transistors, the fifth MOS transistor, the ninth MOS transistor, the tenth MOS transistor, the seventeenth MOS transistor and the eighteenth MOS transistor include PMOS transistors, the sixth MOS transistor, the seventh MOS transistor, the eighth MOS transistor, the eleventh MOS transistor, the twelfth MOS transistor, the thirteenth MOS transistor, the fourteenth MOS transistor, the nineteenth MOS transistor and the twentieth MOS transistor include

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NMOS transistors, the first power supply comprises a positive power supply and the second power supply comprises ground; and

the first node of each of these MOS transistors comprises a source, the second node of each of these MOS transistors comprises a gate, and the third node of each of these MOS transistors comprises a drain.

20. The method of claim 19, wherein the first amplification stage further comprises a fifteenth MOS transistor and a sixteenth MOS transistor, wherein the ninth MOS transistor is connected to the eleventh MOS transistor via the fifteenth MOS transistor, and the tenth MOS transistor is connected to the twelfth MOS transistor via the sixteenth MOS transistor;

first node of the fifteenth MOS transistor is connected to third node of the ninth MOS transistor, second node of the sixteenth MOS transistor is connected to the third node of the tenth MOS transistor, second nodes of both the fifteenth MOS transistor and the sixteenth MOS transistor are connected to the second voltage source, a third node of the fifteenth MOS transistor is connected to the third node of the eleventh MOS transistor, a third node of the sixteenth MOS transistor is connected to the third node of the twelfth MOS transistor; and

the fifteenth MOS transistor and the sixteenth MOS transistor comprise PMOS transistors, and the first node of each of the fifteenth and sixteenth MOS transistors comprises a source, the second node of each of the fifteenth and sixteenth MOS transistors comprises a gate, and the third node of each of the fifteenth and sixteenth MOS transistors comprises a drain.

21. The method of claim 18, wherein the first, the second, the third, the fourth MOS transistors, the fifth MOS transistor, the ninth MOS transistor, the tenth MOS transistor, the seventeenth MOS transistor, the eighteenth MOS transistor include NMOS transistors, the sixth MOS transistor, the sev-

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enth MOS transistor, the eighth MOS transistor, the eleventh MOS transistor, the twelfth MOS transistor, the thirteenth MOS transistor, the fourteenth MOS transistor, the nineteenth MOS transistor and the twentieth MOS transistor include PMOS transistors, the first power supply comprises ground supply and the second power supply comprises a positive power; and

the first node of each of these MOS transistors comprises a source, the second node of each of these MOS transistors comprises a gate, and the third node of each of these MOS transistors comprises a drain.

22. The method of claim 21, wherein the first amplification stage further comprises a fifteenth MOS transistor and a sixteenth MOS transistor, wherein the ninth MOS transistor is connected to the eleventh MOS transistor via the fifteenth MOS transistor, and the tenth MOS transistor is connected to the twelfth MOS transistor via the sixteenth MOS transistor;

first node of the fifteenth MOS transistor is connected to third node of the ninth MOS transistor, first node of the sixteenth MOS transistor is connected to the third node of the tenth MOS transistor, second nodes of both the fifteenth MOS transistor and the sixteenth MOS transistor are connected to the second voltage source, a third node of the fifteenth MOS transistor is connected to the third node of the eleventh MOS transistor, a third node of the sixteenth MOS transistor is connected to the third node of the twelfth MOS transistor; and

the fifteenth MOS transistor and the sixteenth MOS transistor comprise NMOS transistors, and the first node of each of the fifteenth and sixteenth MOS transistors comprises a source, the second node of each of the fifteenth and sixteenth MOS transistors comprises a gate, and the third node of each of the fifteenth and sixteenth MOS transistors comprises a drain.

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